ASSATEAGUE ISLAND NATIONAL SEASHORE

GEOLOGIC RESOURCE MANAGEMENT ISSUES

SCOPING SUMMARY

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August 3, 2005

Wave action at Assateague Island National Seashore. Photograph by Melanie Ransmeier, Geologic Resources Division, National Park Service.

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Executive Summary

A Geologic Resource Evaluation scoping meeting for Assateague Island National Seashore took place in Berlin, Maryland on July 26- 28, 2005. A field trip highlighting the dynamic coastal processes at the seashore followed the roundtable discussion. Scoping meeting participants identified the following list of geologic resource management issues. These topics are discussed in detail on pages 13- 21.

1. Storm effects, coastal vulnerability index, and sea level rise

2. Restoration of unimpaired sediment transport processes and the state of existing transport processes such as wind, waves, longshore drift, and animal and human activities

3. Benthic habitats

4. Landscape and shoreline evolution including the opening and closings of inlets, paleodrainage, overwash zones, barrier island migration, dune field changes, and paludal environments

5. Connections between geology, cultural resources, and flora- fauna patterns

6. Hydrology of Assateague Island including groundwater flow, freshwater-saline water distribution, and hydrogeologic characterization to understand the flow of water beneath and within the park

7. Human impacts including land use and recreation

8. Seismicity including tsunami risk from continental slope submarine landslides

9. Unique features and processes including landscape response to artificially maintained inlets, historic inlets, paleontological resources, and periglacial pingos

10. Disturbed lands such as sand mines, dredging areas, ditches, canals, manmade ponds, artificial berms, hunting camps, grazed areas, boat groundings, hydroclam dredging, and armored shorelines

Introduction

This report briefly describes the general geology of Assateague Island National Seashore (ASIS), including a geologic history of the park, geologic resource management issues in the park, and the status of Geologic Resource Evaluation (GRE) digital geologic mapping projects related to the park. The National Park Service held a Geologic Resource Evaluation scoping meeting for Assateague Island National Seashore in Maryland on Wednesday, July 27 through Thursday, July 28, 2005. The purpose of the meeting was to discuss the status of geologic mapping in the park, the associated bibliography, and geologic issues effecting the park. Products derived from the scoping meeting will include: (1) Digitized geologic maps covering the park; (2) Updated and validated geologic bibliography; (3) Scoping summary (this report); and (4) Geologic Resource Evaluation report which brings together all of these products.

Assateague Island National Seashore was established during President Lyndon B. Johnson's administration on September 21, 1965. The national seashore covers 39,727 acres of coastal plain between Chincoteague, Virginia and Ocean City, Maryland. It is one of the largest protected barrier island environments in the eastern United States. Assateague Island National Seashore protects geomorphologically dynamic landscapes, fragile wetlands, a variety of threatened habitats, and undeveloped beaches.

Map Notes

The Inventory and Monitoring Program and Assateague Island National Seashore identified 20 quadrangles of interest (QOI) (Figure 1). General geologic maps covering parts of the ASIS quadrangles of interest include:

Brooks, J.R., 1990, Mineral resources of Worcester County, Maryland, Maryland Geological Survey, County Mineral Resource Maps, 1:62500 scale (GMAP_ID 3058).

Brooks, J.R., 1990, Mineral resources of Wicomico County, Maryland Geological Survey, County Mineral Resource Maps, 1:62500 scale (GMAP_ID 7113).

Brooks, J.R., 1996, Mineral resources of Somerset County, Maryland, Maryland Geological Survey, County Mineral Resource Maps, 1:62500 scale (GMAP_ID 7118).

Owens, J.P. and Denny, C.S., 1978, Geologic map of Worcester County, Maryland Geological Survey, County Geologic Maps, 1:62500 scale (GMAP_ID 3059).

Owens, J.P. and Denny, C.S., 1979, Geologic map of Wicomico County, Maryland Geological Survey, County Geologic Maps, 1:62500 scale (GMAP_ID 7122).

Owens, J.P. and Denny, C.S., 1984, Geologic map of Somerset County, Maryland Geological Survey, County Geologic Maps, 1:62500 scale (GMAP_ID 7123).

Ramsey, K.W. and Schenck, W.S., 1990, Geologic map of southern Delaware, Delaware Geological Survey, Report 32, 1:100000 scale (GMAP_ID 3060).

Scoping participants are not aware of any large- scale general geologic map coverage for the Virginia portion of ASIS QOIs. Many other maps exist for parts of ASIS QOIs that include coverage of geology, shoreline change, aeromagnetic-gravity, hazard, mineral and mineral potential, geochemical and hydrogeology, surficial, and stratigraphy, etc. These maps are available from agencies such as the U.S. Geological Survey, the Maryland Geological Survey, the Delaware Geological Survey, the Virginia Division of Mineral Resources, and the Geological Society of America.

However, scoping participants agree that traditional geologic maps are not adequate for geologic resource management in the dynamic coastal environment. A need exists for benthic habitat, sediment type and distribution, nearshore- surf zone, sediment thickness, bathymetric, and geomorphic maps of Assateague Island National Seashore. A baseline for monitoring ongoing geomorphic processes and shoreline changes associated with storm events would help the park better predict future patterns of change and manage the resources accordingly.

The Maryland Geological Survey has an ongoing Coastal Bays Sediment Mapping project that covers the northern reaches of Chincoteague Bay and Sinepuxent Bay. David Kranz and Doug Levin have been conducting seismic surveys and obtaining sidescan sonar data for the near shore areas of Assateague Island since

2002. Bob Morton (USGS) recently completed an unpublished geomorphic landform map of Assateague Island.

Mapping with lidar provides vital information in mapping Quaternary age deposits, which is traditionally difficult given the dynamic nature of the barrier island. Lidar surveys are useful for shoreline and beach volume change calculations. Annual lidar surveys at Assateague started in 1998. The use of aerial photographs, erosion rates, as well as seasonal shoreline surveys help the park monitor the changes in shoreline and assist in the management for this resource. Digital aerial photographs exist for the park dating back to 1993. Additional geomorphic landform mapping at a smaller scale within park boundaries would be helpful for park resource management and interpretation.

Mapping Deliverables

With the abundance of geologic data and research pertaining to Assateague Island conducted by numerous institutions, a spatial index of available data to guide future mapping efforts and identify data gaps would be useful for geologic resource management. The Geologic Resource Division may take responsibility for creating this index.

The GRE team also plans to cooperate with the University of Toledo by funding a graduate student to groundtruth and finalize a terrestrial geomorphic landform map of Assateague Island similar to the one recently completed by Bob Morton. The GRE team also hopes to promote near shore zone maps of geomorphology (processes), subbottom structure (with seismic cross sections), sediment type, and bathymetry.

Physiography

Assateague Island is 58 km (36 miles) long and sits off the Atlantic coast of Maryland and Virginia, separated from the mainland by Sinepuxent and Chincoteague Bays. The Ocean City inlet (opened in 1933) sharply truncates the barrier island's northern end and Chincoteague inlet establishes the southern extent. Average elevation is low, about 2 m (6 ft). The highest dunes may reach 10 m (30 ft) above sea level.

Assateague Island National Seashore lies within the Atlantic Coastal Plain physiographic province. In the area of Assateague Island, the eastern United States is divided into 5 physiographic provinces with associated local subprovinces. These are, from east to west, the Atlantic Coastal Plain, the Piedmont Plateau, the Blue Ridge, the Valley and Ridge, and the Appalachian Plateaus provinces.

The Atlantic Coastal Plain province is primarily flat terrain with elevations ranging from sea level to about 100 m (300 ft) in Maryland. Sediments eroding from the Appalachian Highland areas to the west formed the wedge- shaped sequence of soft sediments that were deposited intermittently on the Atlantic Coastal Plain during periods of higher sea level over the past 100 million years. These sediments are now more than 2,438 m (8,000 ft) thick at the Atlantic coast and are continually reworked by fluctuating sea levels and the erosive action of waves along the coastline. Large streams and rivers cross the Coastal Plain province and transporting sediment and extending the coastal plain eastward. Beyond the province to the east the submerged Continental Shelf province extends for another 121 km (75 miles).

Geologic History of Southern Maryland

Proterozoic Era – In the mid Proterozoic, during the Grenville orogeny, a supercontinent formed which included most of the continental crust in existence at that time. The sedimentation, deformation, plutonism (the intrusion of igneous rocks), and volcanism associated with this event are manifested in the metamorphic gneisses in the core of the modern Blue Ridge Mountains (Harris et al., 1997). These rocks were deposited over a period of 100 million years and are more than a billion years old, making them among the oldest rocks known from this region. They form a basement upon which all other rocks of the Appalachians were deposited (Southworth et al., 2001).

The late Proterozoic, roughly 600 million years ago, brought a tensional, rifting tectonic setting to the area. The supercontinent broke up and a sea basin formed that eventually became the Iapetus Ocean. In this tensional environment, flood basalts and other igneous rocks such as diabase and rhyolite added to the North American continent. These igneous rocks were intruded through cracks in the granitic gneisses of the Blue Ridge core and extruded onto the land surface during the break- up of the continental land mass (Southworth et al., 2001). The Iapetus basin collected many of the sediments that would eventually form the Appalachian Mountains and Piedmont Plateau.

Early Paleozoic Era – From Early Cambrian through Early Ordovician time there was another period of orogenic activity along the eastern margin of the continent. The Taconic orogeny (~440- 420 Ma in the central Appalachians) was a volcanic arc – continent convergence. Oceanic crust, basin sediments, and the volcanic arc from the Iapetus basin were thrust onto the eastern edge of the North American continent. The Taconic orogeny involved the closing of the ocean, subduction of oceanic crust, the creation of volcanic arcs and the uplift of continental crust (Means, 1995). In response to the overriding plate thrusting westward onto the continental margin of North America, the crust bowed downwards to the west creating a deep basin that filled with mud and sand eroded from the highlands to the east (Harris et al., 1997). This so- called Appalachian basin was centered on what is now West Virginia.

This shallow marine to fluvial sedimentation continued for a period of about 200 million years during the Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian Periods resulting in thick piles of sediments These sediments were derived from the eroding highlands that rose to the east during the Taconian orogeny (Ordovician), and the Acadian orogeny (Devonian). The Acadian orogeny (~360 Ma) continued the mountain building of the Taconic orogeny as the African continent approached North America (Harris et al., 1997). Similar to the preceding Taconic orogeny, the Acadian event involved land mass collision, mountain building, and regional metamorphism (Means 1995). This event was focused to the north of present day southern Maryland.

<u>Late Paleozoic Era</u> – Following the Acadian orogenic event, the proto- Atlantic Iapetus Ocean completely closed during the Late Paleozoic as the North American continent collided with the African continent. This formed the Appalachian mountain belt we see today and the Pangean supercontinent. This mountain building episode is called the Alleghanian orogeny (~325 – 265 Ma), and was the last major orogeny of the Appalachian evolution (Means, 1995). During this orogeny, rocks of the Great Valley, Blue Ridge, and Piedmont provinces were transported as a massive block westward onto younger rocks of the Valley and Ridge. The amount of compression was extreme. Estimates are of 20- 50 percent shortening which translates into 125–350 km (75- 125 miles) of lateral translation (Harris et al., 1997).

<u>Mesozoic Era</u> – Following the Alleghenian orogeny, during the late Triassic, a period of rifting began as the joined continents began to break apart from about 230- 200 Ma. The supercontinent Pangaea divided into roughly the continents that exist today. This episode of rifting or crustal fracturing initiated the formation of the current Atlantic Ocean and caused many block- fault basins to develop with accompanying volcanism (Harris et al., 1997; Southworth et al., 2001). Thick deposits of unconsolidated gravel, sand, and silt were shed from the eroding mountains. These were deposited at the base of the mountains as alluvial fans and spread eastward to be part of the Atlantic Coastal Plain (Duffy and Whittecar 1991; Whittecar and Duffy, 2000; Southworth et al., 2001).

The amount of material that has been eroded from the Appalachian Mountains, as inferred from the now- exposed metamorphic rocks, is immense. Many of the rocks exposed at the surface must have been at least 20 km (~10 miles) below the surface prior to regional uplift and erosion. The erosion continues today with the Potomac, Rappahannock, Rapidan, James, and Shenandoah Rivers, stripping the Coastal Plain sediments, lowering the mountains, and depositing alluvial terraces and deltas, creating the present landscape. Waves, tides, and currents of the Atlantic Ocean continually rework these sediments along the coast.

<u>Cenozoic Era</u> – Since the breakup of Pangaea and the uplift of the Appalachian Mountains, the North American plate has continued to drift toward the west. The isostatic adjustments that uplifted the continent after the Alleghenian orogeny continued at a subdued rate throughout the Cenozoic Period (Harris et al., 1997). These adjustments may be responsible for occasional seismic events felt throughout the Chesapeake Bay region.

Though glaciers from the Pleistocene Ice Ages never reached southern Maryland (the southern terminus was in northeastern Pennsylvania), the intermittent colder climates of the ice ages played a role in the formation of the landscape at Assateague Island National Seashore. Sea level fluctuations during ice ages throughout the Pleistocene caused the shorelines of all the barrier islands to migrate landward and seaward. During lowstands (sea level drops), the area's rivers would erode their channels exposing the deformed bedrock of the Piedmont Plateau to the west. During oceanic highstands, the river basins flooded, forming large bays, and deposition resulted in deposits of beach sediments west of the park area. At the present time, the island is migrating landward as sea level rises (Toscano et al., 1989).

Dynamic geomorphologic processes including longshore sediment transport, off shore shoal development, tidal fluctuations, powerful storm surges and wave action define the Assateague Island landscape. Because of the responsive nature of this ever- changing landscape, the island is especially vulnerable to anthropogenic alterations. In 1933, the former Fenwick Island was breached by a hurricane and separated by Ocean City Inlet into Fenwick Island to the north and Assateague Island to the south (Underwood and Hiland, 1995). The artificially maintained inlet on the northern end of the island has altered longshore sediment transport patterns resulting in significant shoreline change and accelerated landward migration of the barrier island (Ransmeier, 2005).

Stratigraphy

The Tertiary age (Pliocene) marine Yorktown Formation underlies most of the coastal areas in Virginia and Maryland. This unit contains quartz and feldspar sands mixed with lesser clays and silts and abundant fossils. The upper surface of the Yorktown is erosional and in eastern Maryland, Walston silt and Beaverdam sand were deposited on this surface. The Accomack Member of the Omar Formation is a widespread unit atop the Yorktown. This unit is Late Pleistocene in age. Joynes Neck sand is present in the Virginia coastal areas (Mixon, 1985; Toscano et al., 1989).

The Sinepuxent, Wachapreague, and Ironshire Formations were deposited atop the Omar Formation after a period of erosion. These units are Late Pleistocene in age. The Wachapreague contains well- preserved paleo sand spits and barriers. The Ironshire Formation contains sand and gravel whereas the Sinepuxent Formation contains finer- grained marginal marine sediments. The units above the Yorktown Formation are part of a major shoreline complex deposited oblique to the current barrier island system in the Late Pleistocene (Toscano et al., 1989). These units were emplaced as terraces during periods of fluctuating sea level. Several areas exhibit a transgressive sequence comprised of basal fluvial channel deposits, paludal (pond) layers, estuarine, marsh, lagoonal, back- barrier, and barrier facies, recording local sea level rise (Peebles, 1984).

Surficial sediments at Assateague are constantly shifting. Wave action, storm overwash and eolian processes are among the erosional- depositional forces at work along the shoreline. Sand is the dominant sediment type at Assateague Island National Seashore, often comprising up to 100% of sediment samples (Toscano et al., 1989). Muddy deposits exist in local pockets throughout the area. These likely represent reworked back- bay and marsh deposits. Gravel lenses are the result of high- energy events. They are only present in local shoal areas.

Significant Geologic Resource Management Issues

1. Storm effects, coastal vulnerability index, and sea level rise

Storm events have extreme effects on the landscape at Assateague Island and are a vital force in maintaining the natural balance of the barrier island. Storms create inlets, cause cross- island overwash, replenish the sediment supply, cause erosion, and reshape the shorelines. Nor'easters and occasional hurricanes are the primary storm system types affecting Assateague.

Sea level rise is affecting all of the eastern United States. Local relative sea level rise is estimated at 3 mm/year (0.1 inches/year). Given the low relief at Assateague (0.5 – 1.5 m, 1.6 to 5 ft) as well as local subsidence from glacial rebound, if present rates continue rising seas could begin to submerge lower areas and inundate backbay wetlands in less than 2000 years.. While slowing the rate of sea level rise is beyond the resources of the park, monitoring sea level change, evaluating and predicting impacts on the park's landscape are valid management issues. Baseline data and conditions are necessary before monitoring can proceed.

Research and monitoring questions and suggestions include:

- Is there any way to save the subaerial habitat from rising seas?
- What is the exact local rate of sea level rise?
- Monitor and measure the relationship between water level flux and elevations to determine an exposure/submergence index (i.e. 100% of the time exposed versus 0% of the time exposed).
- Quantitatively define the terms subtidal, supratidal, and intertidal units to use for future predictions and relate these to the local elevations and annual regime of water fluctuations.
- How fast will the park be submerged?
- How should facilities be sited in light of sea level rise?
- Perform comprehensive shoreline surveys at least twice a year to establish a baseline inventory to aid future monitoring efforts of coastal changes.

2. Restoration of sediment transport and existing transport processes

The Army Corps of Engineers works to maintain the Ocean City Inlet that opened during in a 1933 storm event. These efforts include jetties that extend along the northern end of Assateague Island. The dynamics around the inlet are well- documented by the Corps. The inlet has caused extreme changes to the northern end of Assateague Island and the shoreline of Sinqpuxent Bay (Underwood and Hiland, 1995). Shoreline has migrated westward more than 350 m (1,050 ft) and has resulted in significant unnatural geomorphological, habitat, and biotic changes. Approximately 6.6 million cubic meters of sand is missing from the system at Assateague Island due to the inlet and the effect of this loss extends 11 km (6.5 miles) down the island (NPS, 2001). Sand supply and sea level are perhaps the two major determining factors in the evolution of the landscape at Assateague Island. When human activity interferes with either of these two variables, significant changes occur.

Restoration plans devised by the Army Corps of Engineers, the National Park Service, the state of Maryland, Worcester County, Maryland, and the Town of Ocean City, Maryland include a one- time infusion of sand to replace a large portion of the overall sand loss on the northern end, and the re- establishment of a “natural” sediment supply to the island (NPS, 2001).

Slope erosion is not a major issue at Assateague as the relief on the island is generally between 0.5 to 1.5 m (1.6 - 5 ft). Small changes in elevation are significant on such a low landscape. Waves are important for moving sand, eroding dunes, creating scarps, creating additions to the island, and longshore sediment transport, whereas tides are most influential in the marsh environments of the backbay areas and ebb and floodtidal deltas.

Sediment transport patterns are largely seasonal depending on storm seasons and higher winds at certain times of the year. Aeolian processes move sediment in dunes and sheets across the landscape at Assateague. Winds are generally from the northeast, northwest, and south- southwest. Wind transports fine grained sediments leaving larger pieces, natural or anthropogenic, behind. In some areas this resembles desert pavement. These wind blown sediments affect facilities, roads, and buildings. Vegetation planted to anchor sands and grazing horses are changing the local landscape at Assateague, typically creating dunes and removing stabilizing plants, respectively. Some dunes, such as the dune in the State Park campground, are maintained and others are eroding away.

Research and monitoring questions and suggestions include:

- Collect near shore- surf zone sediment thickness data.
- Obtain offshore wave data to model sediment movement through the Ocean City inlet.
- What are the ramifications of mining offshore sand shoals for beach replenishment?
- Obtain off- and near- shore data including bathymetry, sediment type, and cores.
- What is the sediment contribution from canals and surrounding development?
- Are there any true streams at Assateague Island?
- Profile dunes twice annually, perhaps supplement with lidar surveys.

3. Benthic habitats

From the wave driven Atlantic shoreline to the calmer backbay estuarine areas, many subaqueous habitat types exist at Assateague Island National Seashore. The different environments are strongly related to minute changes in elevation. Environments can change within centimeters of topographic relief. Given the coverage of mapping at the park, traditional surficial maps are not sufficient for complex management decisions at Assateague. An interdisciplinary approach to mapping is critical to producing a useful product for resource management. Useful data to collect for this effort includes lidar surveys, satellite imagery, multibeam mapping, bathymetry data, water quality and circulation, shoreline change data, pre- and post- storm comparisons, and oceanographic data (waves, tides, currents, turbidity, temperature salinity, sediment transport patterns, and species distributions). Mapping anthropogenic, supratidal, intertidal, subtidal, and coastal features would all be helpful. This ecosystem approach integrates biological, physical, cultural, and oceanographic variables.

Several species of seagrasses were nearly destroyed during blight in the 1930's. Today these populations have rebounded, but are threatened by boaters and macroalgae. Macroalgae blooms threaten the subaqueous habitats in the park and are typically related to nutrient loading from anthropogenic sources. Oyster, scallop and other mollusk beds are also threatened.

Research and monitoring questions and suggestions include:

- Cooperate with the Maryland Coastal Bays Sediment mapping project to obtain grain size, trace metals, nutrients, sedimentation rates, etc.
- Map sediment distribution patterns.
- Map shoals and offshore sand resources.
- What is the groundwater input to the benthic habitats at Assateague? Is nutrification of the groundwater affecting benthic habitats at Assateague?
- Promote offshore mapping.

4. Landscape and shoreline evolution

Short- term landscape evolution at Assateague Island is very important to understand for resource management because the dynamic nature of the system leads to rapid, widespread changes. Inlets may open and close within single storm events. At least 10 inlets have segmented the island since 1690. These inlets were closed quickly by rapid sediment transport typical of a barrier island system.

The sediments at Assateague record large tidal inlet channels in the past. In the past 500 years, evidence suggests Assateague has evolved into a linear island from an island chain. An old Potomac paleochannel, the Chincoteague Byte, causes the hook at the southern end of Assateague Island. The 4- 5 km (2.5- 3.1 miles) wide, 50 m (165 ft) deep coarser grained channel sediments anchor the landform.

Sea level changes have caused the island to move seaward, landward, and stall several times in the past 2,000 years. A working knowledge of the landscape change, including dune field changes, over the last 5,000 years would provide meaningful standards for comparison for resource management.

There are many shoreline types at Assateague Island including beaches, tidal inlets, artificially maintained inlets, paludal shores, backbay estuaries, and wetlands. Hundreds of small seasonal ponds exist on the island and the majority contains water for 9- 10 months of the year. These areas offer unique biological niches on the island.

Research and monitoring questions and suggestions include:

- Map locations of freshwater ponds. Why are there fresh and saltwater ponds at Assateague and is there a pattern to their distribution?
- What is the thickness of the freshwater lens beneath Assateague?
- Study paleoinlets to determine any patterns and date the age of Assateague Island.
- Study paleodrainage using on and offshore indicators.
- Identify geologic features as they are formed by processes.
- Promote shoreline studies on Virginia end of the island.
- Promote studies to evaluate the inner shoreface of Assateague Island.
- Can a landscape evolution model predict future changes and shapes?
- Focus on mapping processes with a time scale as opposed to features of the landscape, which quickly change.
- Obtain cross sectional information for the Island and nearshore areas.
- Why is Assateague Island changing to a linear island instead of a chain? What caused the chain to barrier island transition?
- Increase landscape studies on the northern end of the island.

5. Connections between geology and other disciplines

Geology forms the basis for habitats at Assateague Island. Distributions of plants and animals are determined by many factors. Manmade structures influence vegetation distributions and patterns at Assateague. Physical attributes in conjunction with climatic patterns influence this distribution. Mapping of the physical attributes and processes is a first step in understanding these connections.

Several offshore archaeological sites exist at Assateague. These require further study. Given the long period of human habitation and influence at the island, this potential cultural resource remains to be fully explored.

Assateague Island protects many acres of unique and vital habitat for several species of birds. The piping plover requires a natural balance between open, overwashed areas, and protective vegetative cover. Instead of the natural active dunes and overwash zones, areas on the northern end of Assateague were restored with an artificial berm of coarser material that was built in 1998 and rebuilt in 2002. This high area is relatively unvegetated and resists overwash. The birds nest there, but their young have to travel too far for forage areas. Areas behind the berm are supporting too much vegetation. Horses and bats take advantage of the freshwater ponds dotting the island.

Research and monitoring questions and suggestions include:

- Inventory all archaeological sites at Assateague Island and relate to geologic influences.
- What is the time scale for the age of Assateague Island?
- What is the best way to preserve piping plover habitat?
- How should horses be managed to protect water quality and prevent overgrazing?

6. Hydrology of Assateague Island

Resource managers need to understand how water is moving through the hydrogeologic system into, under, and from the park. Pockets of freshwater underlie the park as microwatersheds. The freshwater lens is discontinuous. This segregation is a function of the geomorphological changes throughout the island's history, especially storm- induced inlet creation. Knowledge is limited about the amount of flow and partitioning between them. Management also needs to understand how the water table might change over time.

The interaction between groundwater flow and overall fresh water and marine ecological quality must be quantitatively determined at Assateague. Visitor uses and surrounding development are increasing the levels of certain substances in the water at the park. The northern and southern coastal bays are fed by relatively small watersheds. These areas are poorly circulated (it takes approximately 100 days to flush a contaminant out of the system). An understanding of how the water currents and geology interact is vital to understanding contaminant flow through the park.

Research and monitoring questions and suggestions include:

- What is the groundwater flow pattern within and beneath the park?

- How many wells are necessary to model the hydrogeologic system at the park?
- Characterize the groundwater interface between the salt and fresh water boundaries. Determine the fresh water discharge into Sinepuxent and Chincoteague Bays.
- Install more wells for cores, hydrogeologic characterization, and monitoring.
- Is the wildlife at Assateague causing a water quality issue in the seasonal ponds?
- Perform dye tests to look at the hydrogeologic effects of local geologic structures on the hydrology.
- Are CFC levels elevated in the groundwater at Assateague Island National Seashore?
- Create hydrogeologic models for the park to better manage the groundwater resource and predict the system's response to contamination.
- Comprehensively map and monitor water and soil quality at all wetlands within the park. This creates a baseline level of ecosystem health to use for understanding future changes.

7. Human impacts including land use and recreation

Humans began settling the Assateague Island area in the late 1600's to early 1700's. Native American groups including the Pocomokes, Chincoteagues, and Assateagues of the Nanticoke tribe were the first humans to use the island. English colonists settled during the late 1600's and remained on the island throughout the 19th century (Underwood and Hiland, 1995). Their hunting, farming and homestead activities created an unnatural landscape that locally persists today. Prior to the 1933 opening of the Ocean City Inlet, housing developments and a railroad were connected to present day Assateague Island. Minor irrigation features, mosquito ditches, roadways, removal of soil, grazed areas, are among the anthropogenic features emplaced during this time. A March 1962 storm destroyed approximately 32 of the 50 or so remaining dwellings on the island (Underwood and Hiland, 1995).

Human impacts continue today as pipelines, power lines, roads, buildings, trails, visitor use areas, invasive species, acid rain, and air and water pollution take their toll on the landscape. The area surrounding Assateague Island is becoming increasingly populated. As development continues, conservation of any existing wetland- shore- meadow community types becomes a critical concern. Understanding the geology beneath the biotic communities becomes vital to their management. Recreational use in the park is high as the beach and shoreline areas are popular for swimming, sunbathing, hunting, recreational shellfishing, off- road vehicle use, hiking, camping, fishing, and wildlife viewing (NPS, 2001). Resource management of these impacts is an ongoing process.

Research and monitoring questions and suggestions include:
- Cooperate with local developers to minimize impact near park areas.
- Consult conservation groups regarding cooperative efforts to increase the areas of relevant parklands and protect more of the region around the island from development.
- Promote environmentally sound methods of developing land parcels including partial clearing of trees and proper construction of stable slopes.
- Map pipeline locations.
- Is it prudent to establish a beach walk as an attempt to armor the shoreline and also educate the visitor?
- Create a storm interpretive program.
- Should the unnatural landscapes created by early settlers be remediated?
- Are soils becoming more acidic due to acid rain?

8. Seismicity including tsunami risk

A minor local fault exists one mile inland of Assateague Island. Assateague is located in a coastal hinge zone. The Chesapeake Bay impact structure (the outer ring of which is to the south of the park) is still downloading and has caused frequent small magnitude earthquakes for the past million years. Earthquakes may cause significant damage to buildings, fences and other structural features at Assateague Island.

Tsunamis, though rare, are a real possibility at Assateague. The most likely triggers would be submarine landslides off the relatively steep continental slope. In this situation, a triggered slide would fail, sending a large portion of marine sediment cascading down the slope face. This abrupt movement of material causes the overlying water column to be displaced resulting in large waves emanating from the point of origin.

Research and monitoring questions and suggestions include:
- Promote the development of an active seismic network for the area.
- Evaluate risk for tsunami and shoreline damage due to earthquake activity.
- Evaluate cultural features and fragile habitats at risk for damage during infrequent seismic events.

9. Unique features and processes

On August 23, 1933, a new inlet, approximately 3 m (9 ft) deep cut through Fenwick Island separating it from Assateague. Almost immediately, locals and fishermen took advantage of this new passageway from the bay to the Atlantic Ocean. Construction of a northern jetty was completed in 1934, and the southern jetty was finished in 1935. Since 1938, continued structural modifications and upgrades are necessary to keep the inlet open and the jetties intact. These structures are composed of layers of bedding material, corestone, capstone, and precast concrete units (Underwood and Hiland, 1995).

The establishment of artificial jetties and breakwaters around Ocean City Inlet had immediate effects on the northern end of Assateague Island. The continuity of local and longshore sediment transport processes was interrupted. The sediment starved shoreline south of the inlet has migrated dramatically shoreward. Shoreline recession rates for the northern end of Assateague Island ranged from 11 m/year (36 ft/year) to 12.2 m/year (40 ft/year) from 1934 to 1983 (Stauble, 1994). In addition to this, a significant accumulation of sand in the inlet shoal areas developed. The immediacy of these effects highlights the dynamic nature of the geomorphic processes at Assateague Island.

Inlets at Assateague are typically created by elevated storm surges and above normal wave forces during hurricanes and nor'easters. Physical characteristics such as barrier width, barrier height, depth and size of adjacent lagoon, number of current inlets in nearby areas, and the duration and magnitude of the storm in question determine the vulnerability to inlet creation of a particular reach of barrier island (Underwood and Hiland, 1995). Erosive energy must be focused on a particular shoreline area to excavate enough sediment to open an inlet. At least 10 inlets have briefly opened along Assateague Island since the early 1800's. Their names include North Beach, Sinepuxent, Fox Hill, Winter Quarter, Slough, Green Run, and Pope Island inlets.

Among the less recognized geologic issues at Assateague are paleontological resources. Paleontological resources are not listed among the park's enabling legislation. A paleontological survey was completed by Jeff Kenworthy and Vince Santucci in 2003 as part of the Paleontological Resource Inventory and Monitoring study of the Northeast and Coastal Barrier Network (NPS, TIC# D-340).

Periglacial pingos dot the landscape in the northern Delmarva Peninsula area. Pingos are created when groundwater freezes and expands, thereby pushing soil into a mound that subsequent erodes. When the ice melts, the eroded soil forms 1 to 2 m (3- 6 ft) rims around a central depression. These features may be 10's of meters across. Pingos and other periglacial features at Assateague are remnants of the colder climates during Pleistocene glacial periods.

Research and monitoring questions and suggestions include:

- How does the north end of the island relate geomorphologically to Ocean City?

- Highlight the dramatic landward migration and thinning of the north end of the island as a result of the Ocean City Inlet stabilization.
- Promote studies dating the oldest section of the island as well as historic inlets.
- Incorporate paleontological resources into interpretive programs.

10. Disturbed lands

Before Assateague Island was protected as a National Seashore human activities on the island included hunting, established camps, settlements, and development of several roads. In addition, ditches were dug for mosquito management and several of the islands ponds are suspected to be anthropogenic. Canals were dug, roads excavated, and dikes created to allow humans better access around the backbay wetland hunting areas. These features as well as heavy grazing interrupt the hydrology of the salt marshes. Armored shorelines (wood and stone groin fields) and jetties affect sediment transport. Groins were built north of Assateague Island as early as 1922.

Small- scale sand mines exist on the island. Most, if not all, of these are inactive. Sand (of the sand bypass program) for beach replenishment is mined primarily from the ebbtidal delta, east and south of the Ocean City Inlet jetty system. Material is also derived from the floodtidal delta. Care must be taken to avoid replenishing the shoreline of Assateague with relatively coarse sand because this tends to unnaturally anchor certain reaches of the shoreline.

Sea grasses grow in shoals and channels in the backbay wetland areas of the park and tidal flats in Chincoteague Bay. Boating vessels traveling through these beds often ground and create propeller scars in the substrate. Deeper cuts often fill with drift algae and other debris. Restoration options for the seagrass beds include resedimentation, sediment stabilization, and transplanting. Hydroclam dredging in the Chincoteague and Sinepuxent bays is affecting benthic habitats

Research and monitoring questions and suggestions:

- Are visitors affecting sediment transport and the hydrologic system at the park?
- Should visit limitations be instigated by the park to reduce anthropogenic erosion?
- Develop an interpretive exhibit specific to the disturbed areas of the park in connection with the geology for visitor information.
- Develop an interpretive program highlighting the cultural features of the landscape including mosquito ditches.

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Map of Assateague Island National Seashore